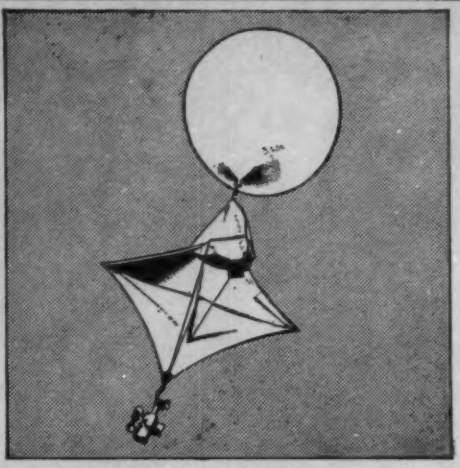
Met.O.785
METEOROLOGICAL OFFICE

the meteorological magazine

MARCH 1967 No 1136 Vol 96
Her Majesty's Stationery Office



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THE METEOROLOGICAL MAGAZINE

Vol. 96, No. 1136, March 1967

551.589.1(41/42):519.2

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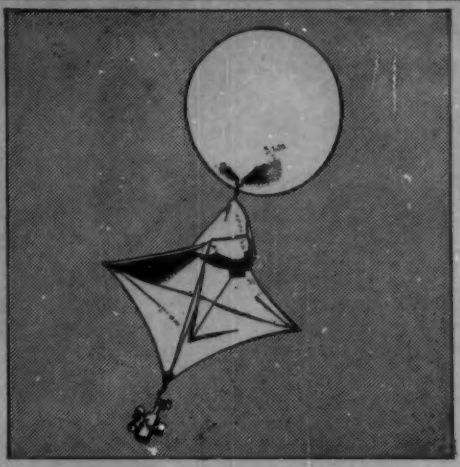
By R. MURRAY

Introduction.—Synoptic indices of progression, meridionality and cyclonicity (for brevity, *P*, *M* and *C* indices), based on Lamb's catalogue[1] of daily synoptic types over the British Isles, have been presented by Murray and Lewis.[2] The *P*, *M* and *C* indices for each month from 1873 to 1964 have been arranged in order of magnitude and classified in terciles for each index (i.e. in three classes for each index with approximately equal numbers in each class, tercile 1 being low values of index), and it seemed worth carrying out an exploratory examination of the indices for possible sequential relationships.

The different *P*, *M* and *C* indices (in terciles) are not significantly associated in adjacent months, although slight persistence is in evidence at certain times, especially with the *P*-index in winter and summer months. However, it was thought that there might be significant differences in frequency of occurrence of the terciles of the cyclonicity index (*C*) after markedly contrasting types of months as specified by the *P* and *C* indices. Nine combinations of *P* and *C* in terciles are possible, but only those which involve terciles 1 and 3 (i.e. $P_1\ C_1$, $P_1\ C_3$, $P_3\ C_1$ and $P_3\ C_3$, where P_1 is tercile 1 in *P*, etc.) show sufficiently different synoptic characteristics. Therefore, each month specified by one or other of these four combinations of *P* and *C* was selected, and the *C*-index in each of the subsequent three months was noted.

The most interesting fact to emerge from an examination of the contingency tables was the tendency for non-progressive, cyclonic (i.e. $P_1\ C_3$) Junes to be followed by C_1 Septembers (7 C_1, 2 C_2 and no C_3), and for progressive, cyclonic (i.e. $P_3\ C_3$) Junes to be followed by C_3 Septembers (3 C_1, 3 C_2 and 8 C_3). This suggested relationship seemed worth further examination. Otherwise little of significance emerged, although a few interesting persistence and anti-persistence tendencies over one or two months were suggested, mostly involving non-progressive, anticyclonic ($P_1\ C_1$) initial months: e.g. after 15 $P_1\ C_1$ Mays there were 8 C_1, 5 C_2 and 2 C_3 Junes; after 13 $P_1\ C_1$ Decembers C_3 occurred only three times in January and two times in February; after 14 $P_1\ C_1$ Septembers there was some anti-persistence in October (only 2 C_1 cases) and November (only 3 C_1 cases).



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The most interesting fact to emerge from an examination of the contingency tables was the tendency for non-progressive, cyclonic (i.e. $P_1\ C_3$) Junes to be followed by C_1 Septembers (7 C_1, 2 C_2 and no C_3), and for progressive, cyclonic (i.e. $P_3\ C_3$) Junes to be followed by C_3 Septembers (3 C_1, 3 C_2 and 8 C_3). This suggested relationship seemed worth further examination. Otherwise little of significance emerged, although a few interesting persistence and anti-persistence tendencies over one or two months were suggested, mostly involving non-progressive, anticyclonic ($P_1\ C_1$) initial months: e.g. after 15 $P_1\ C_1$ Mays there were 8 C_1, 5 C_2 and 2 C_3 Junes; after 13 $P_1\ C_1$ Decembers C_3 occurred only three times in January and two times in February; after 14 $P_1\ C_1$ Septembers there was some anti-persistence in October (only 2 C_1 cases) and November (only 3 C_1 cases).

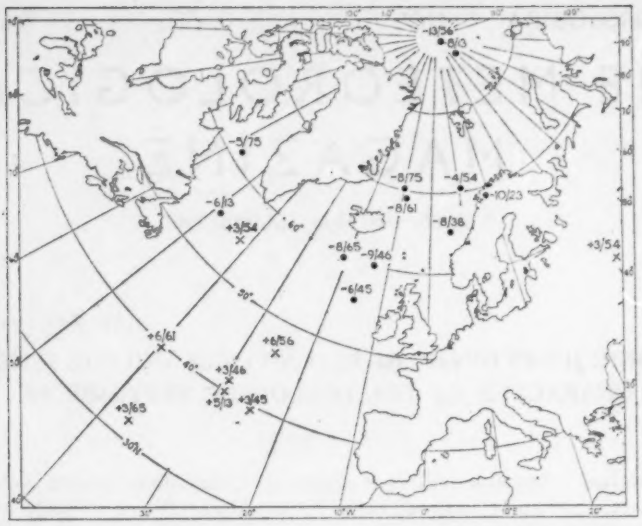

FIGURE 1—MAIN MONTHLY PRESSURE ANOMALY CENTRES FOR PROGRESSIVE, CYCLONIC (D_2 C_2) JUNES OVER THE BRITISH ISLES (CENTRES LESS THAN 3 MB OMITTED) 1873–1964

. Negative anomalies x Positive anomalies

Anomaly (mb) / year of occurrence

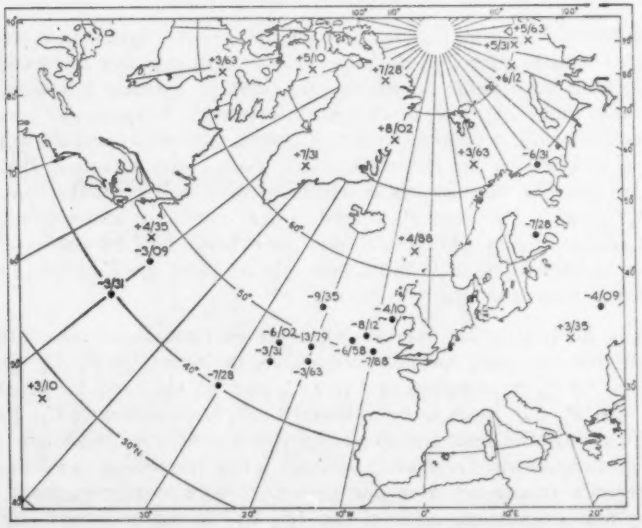

FIGURE 2—MAIN MONTHLY MEAN PRESSURE ANOMALY CENTRES FOR NON-PROGRESSIVE, CYCLONIC (D_1 C_2) JUNES OVER THE BRITISH ISLES (CENTRES LESS THAN 3 MB OMITTED)

. Negative anomalies x Positive anomalies

Analysis of cyclonic Junes.—The *P*-index gives a rough idea of the zonality of the circulation near the British Isles, but it was thought desirable to obtain another objective index to represent the zonal flow over the north-eastern Atlantic. This was done by measuring the monthly mean surface pressure difference (*D*) between 50°N and 60°N averaged over longitudes 0°, 10°, 20° and 30°W for each June back to 1873. From the set of *D* values the tercile boundaries were noted. Thus each June was classified in terciles 1, 2 or 3 in index *D* (low tercile numbers signify the least progressive class).

Approximately one-third of all the Junes were of course C_3 type, i.e. cyclonic; 9 cyclonic Junes were in the top category of progressiveness as measured by index *D* (i.e. 9 D_3 C_3 types), whereas 11 cyclonic Junes were in the bottom category of progressiveness (i.e. 11 D_1 C_3 types). That there are two types of broad-scale circulation in cyclonic Junes corresponding to the D_3 C_3 and the D_1 C_3 groups may be readily seen from Figures 1 and 2. Figure 1 shows the locations of the main positive and negative monthly mean pressure anomaly centres for the progressive, cyclonic Junes (i.e. D_3 C_3). Evidently the negative anomaly centres are generally north of about 55°N and the positive anomaly centres are south of this latitude (actually south of 47°N between 40°W and 40°E), a distribution consistent with an enhanced westerly circulation over the north-east Atlantic. On the other hand, Figure 2 gives the positions of the significant anomaly centres for the D_1 C_3 Junes; and in this case the negative anomaly centres are mostly in middle latitudes and the positive anomaly centres in high latitudes, a distribution consistent with a weaker than usual westerly circulation over the north-east Atlantic.

Cyclonicity after cyclonic Junes.—The patterns of cyclonic behaviour over the British Isles each month after (*a*) progressive, cyclonic Junes and (*b*) non-progressive, cyclonic Junes are shown in Table I.

TABLE I—FREQUENCY OF TERCILES OF *C*-INDEX IN JULY, AUGUST AND SEPTEMBER FOLLOWING CYCLONIC JUNES OF CONTRASTING TYPE

(*a*) After progressive, cyclonic Junes (D_3 and C_3).

	July	Aug.	Sept.
C_1	1	4	0
C_2	4	2	2
C_3	4	3	7

(*b*) After non-progressive, cyclonic Junes (D_1 and C_3).

	July	Aug.	Sept.
C_1	2	1	9
C_2	2	6	1
C_3	7	4	1

It is evident from Table I that there is a tendency for persistence of C_3 type into July in both cases. However, the most interesting feature of Table I is the pronounced differences in frequencies of synoptic type in September between the two classes.

In Table II are listed the Septembers referred to in Table I, together with the dates of those Junes with top and bottom terciles of *D* associated with tercile 2 of the *C*-index.

Table II shows that if the cyclonicity requirements in June are relaxed so as to include Junes in the middle tercile (i.e. C_2), the connexion between June and September is much less definite.

TABLE II—YEARS SELECTED ACCORDING TO VARIOUS COMBINATIONS OF INDICES D AND C IN JUNE RELATED TO INDEX C IN SEPTEMBER (INDICES IN TERCILES)

SEPTEMBER	JUNE $D \geq 6$ mb (progressive)		JUNE $D \leq 2{\cdot}5$ mb (non-progressive)	
	C_3	C_2	C_3	C_2
C_3	1965 (7) 1961 1946 1956 1938 1954 1913	1937 (4) 1918 1882 1881	1955 (2) 1904	1935 (1)
C_2	1945 (2) 1875	1952 (4) 1922 1919 1917	1957 (4) 1951 1920 1905	1958 (1)
C_1	(0)	1890 (1)	1900 (4) 1897 1880 1878	1963 (9) 1931 1909 1928 1902 1912 1888 1910 1879

Figures in brackets show the total number of years under each classification.

A brief examination was made of monthly mean surface pressure maps for July, August and September. In the first class (i.e. progressive, cyclonic Junes) the main low pressure centres in July were in high latitudes, generally from Iceland to Labrador (one centre was over Finland). In August the main lows in five years were over Iceland or between Iceland and west Norway (i.e. farther east than in July) in a situation fairly typical of unsettled weather over the British Isles in this month ; another group of four centres was near south Baffin Land, sufficiently far away to ensure more settled weather than is usual in August over the British Isles. In September most of the lows were in the southern Norwegian Sea or to south-west of Iceland, thus ensuring disturbed weather over the British Isles.

In the second class (i.e. non-progressive, cyclonic Junes) the main lows were in higher latitudes in July than in June, mostly around the central and northern Baltic and over east Iceland, that is farther east than in the first class of low centres in July. In August the main lows were generally in a belt from north-east of ocean weather station 'C' to Scandinavia. However, in September the main lows were mostly far from the British Isles, in or near the Davis Strait and near northern Russia (the only two exceptions were over east Iceland and about 400 miles north-east of ocean weather station 'C').

Discussion.—It might be thought that small shifts in the tercile boundaries would bring additional years into the two classes of Junes, and that the Septembers of these years might be radically different from those shown in Table I. There were in fact six years (1882, 1900, 1919, 1950, 1952 and 1964) at the top of the C_2 class of Junes ; the D-index was tercile 3 in 1882, 1919 and 1952, tercile 2 (but just outside tercile 3) in 1950 and 1964 and tercile 1 in 1900. Thus five additional Junes might be regarded as progressive and cyclonic ; these Junes were not followed by C_1 Septembers. June 1900, which might be taken as a non-progressive, cyclonic June, was followed by a C_1 September. Thus the addition of these six marginal Junes does not weaken the relationships suggested by Table I. As regards the D-index, there were four Junes at the top of tercile 2 ; two of these years (1908, 1948) were also cyclonic (C_2) and neither was followed by a C_1 September. Moreover there were six Junes at the bottom of tercile 2 in index D ; two of these (1916, 1926)

were cyclonic (C_3) and neither was followed by a C_3 September. Hence a slight shift in the tercile boundaries of the *D*-index does not appear to affect the relationships.

If the *C*-index in September were entirely independent of the June circulation then one would expect 3 cases in each of the cells of the September contingency table following the first class of Junes, and about 4 cases in each cell after the second class of Junes. Using these expected results a chi-square test applied to the 3 × 2 contingency table for September shown in Table I suggests that there is only about one chance in a 1000 that the frequency distribution shown in the September contingency table could have occurred in a random selection. That the chi-square test can be applied to contingency tables containing small numbers of data and expected cell-frequencies less than five has recently been confirmed by Craddock[3] for a 3 × 3 table and by Craddock and Flood (unpublished note) for a 3 × 2 table. However it might be argued that a random selection was not in fact made, since other pairs of circulation types for other months were cursorily looked at in a preliminary examination, so that there might be an appreciably greater probability of the results occurring by chance than the 0·1 per cent probability already mentioned. To some extent this is a legitimate criticism. On the other hand, it can also be maintained that the data employed in the June/September case are drawn from a certain population, whilst other samples at other times of the year are drawn from different populations. This contention derives support from the fact that the sources and sinks of heat and the feed-back effects between circulation and underlying surface are not the same in all months of the year.

In spite of some uncertainty about their statistical significance and the lack of a convincing physical explanation, it seems worth reporting these empirical results. To sum up, the data suggest that progressive, cyclonic Junes (as defined in this note) tend to be followed by Septembers which are more cyclonic (or less anticyclonic) than usual ; whereas non-progressive, cyclonic Junes tend to be associated with Septembers which are more anticyclonic (or less cyclonic) than usual over the British Isles.

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3. CRADDOCK, J. M.; Testing the significance of a 3 × 3 contingency table. *The Statistician, London*, **16,** 1966, p. 87.

551.515.7

A NOTE ON ANALYSIS OF ANTICYCLONES

By J. FINDLATER

Introduction.—Problems of forecasting local weather changes in anticyclonic conditions are often tackled by analyses of the limits of cloud and fog systems, inversion heights, haze streams or local wind régimes, and meso-scale discontinuity lines located in this way can be followed from chart to chart on many occasions. Few anticyclones are homogeneous, as illustrated in an earlier analysis[1] where marked horizontal temperature gradients were shown to exist near the level of the subsidence inversion. Although many such small-scale features can be neglected when problems of large-scale motion are being

considered this is not necessarily so for detailed local forecasting, and analyses of small-scale features, delineated by discontinuity lines, have long since proved their usefulness.

In addition to systems of temperature, wind and cloud, however, some insight into the structure and shape of anticyclones can be gained from a detailed analysis of surface pressures when an anticyclone lies over a land area where many reports of MSL pressure are available. For example, Figure 1 shows an anticyclone over the United Kingdom at 0000 GMT on 28 April 1960. Isobars have been drawn carefully at intervals of one millibar, using half-millibar isobars as guidance lines in difficult areas. This analysis shows the central area of the anticyclone to be composed of a central cluster of individual cells separated by minor troughs which spiral outwards from the central area. Some of the troughs link up with frontal troughs and others appear to be the remnants of old frontal troughs which were engulfed during the growth of the anticyclone.

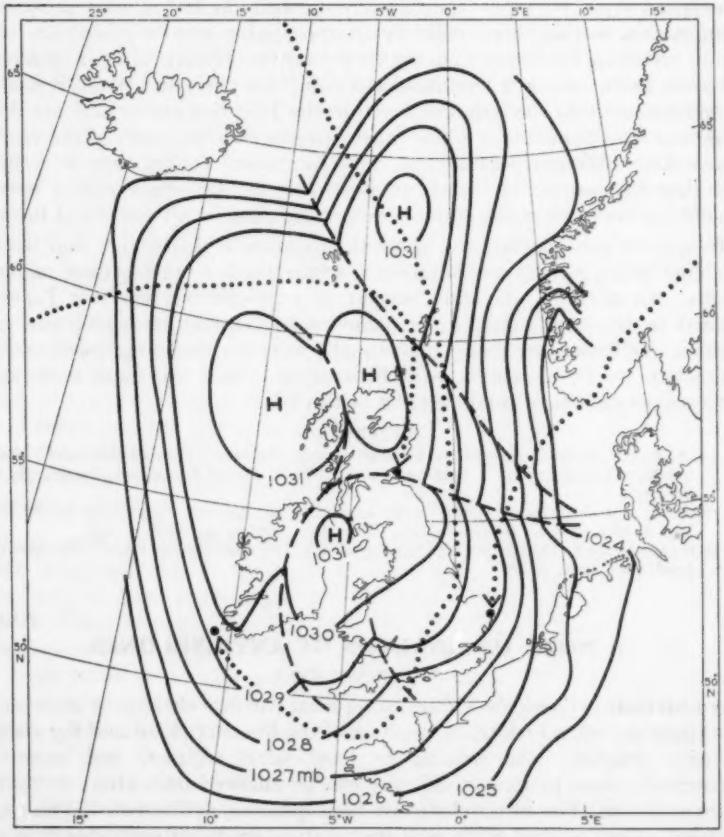

FIGURE 1—DETAILED ANALYSIS OF AN ANTICYCLONE AT 0000 GMT ON 28 APRIL 1960 SHOWING A CLUSTER OF CELLS IN THE CENTRAL AREA

——— Isobars at 1 mb intervals — — — Trough lines

. . . . . Trajectories of air at 2000 feet

Figure 2 shows the same anticyclone 12 hours later, at which time it is apparent that the individual cells of the central cluster have tended to circulate around each other, and the troughs separating them can still be located.

Geostrophic trajectories of the air at 2000 feet showed that at least two air masses were detectable on this occasion although the air had to be tracked for two to four days for positive identification. Some of the trajectories are shown in Figures 1 and 2. The meshing together of cold air from Scandinavia and the area to the north of Iceland with warmer air from mid-Atlantic resulted in alternate masses of the two types reaching eastern England.

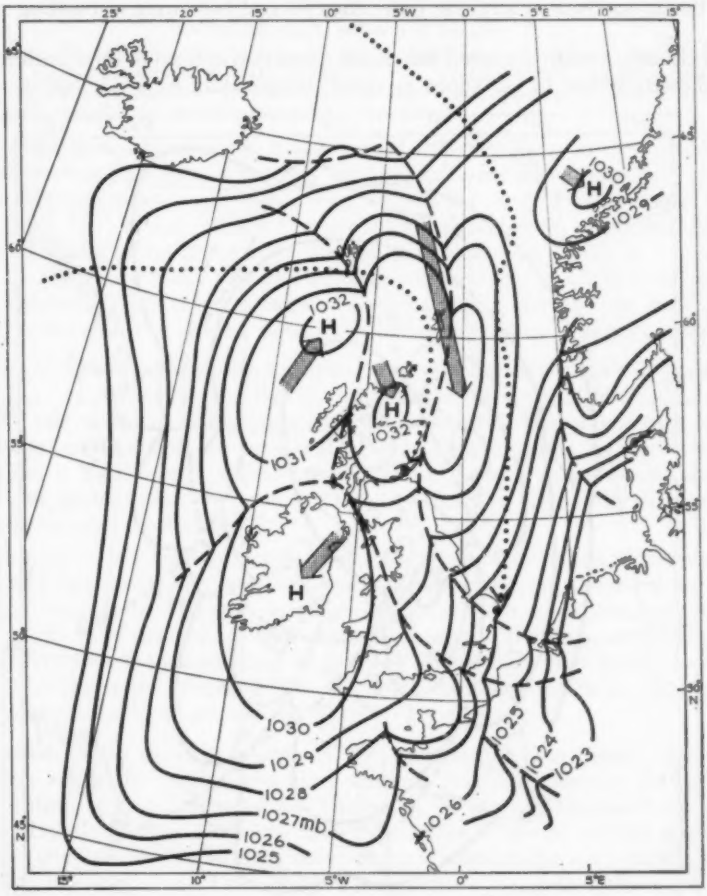

FIGURE 2—DETAILED ANALYSIS OF AN ANTICYCLONE AT 1200 GMT ON 28 APRIL 1960 SHOWING THE 12-HOUR DISPLACEMENT OF CELLS IN THE CENTRAL CLUSTER

——— Isobars at 1 mb intervals — — — Trough lines

..... Trajectories of air at 2000 feet

Broad arrows show the 12-hour displacement of centres.

Four other anticyclones have been analysed in the same way and were found to have a similar pattern of cell clusters in the central area — cells which first appeared on the northern or eastern flanks of the anticyclone behind a trough line and which then spiralled in clockwise fashion to join the central cluster. This type of pattern was most distinct during the growth period of the anticyclone. During periods of decay detailed analysis was much more difficult and patterns in the central area were diffuse.

Figure 3 shows schematically the way in which an individual cell circulated to join a cluster, a process which occurred twice during the period 25–28 April 1960. The schematic diagram may be considered also as representing a model of the anticyclone at any one time when several cells were circulating within it.

It is not presently known if the cluster formation noticed in these anticyclones is directly linked to variations in cloud, temperature or wind, but increased

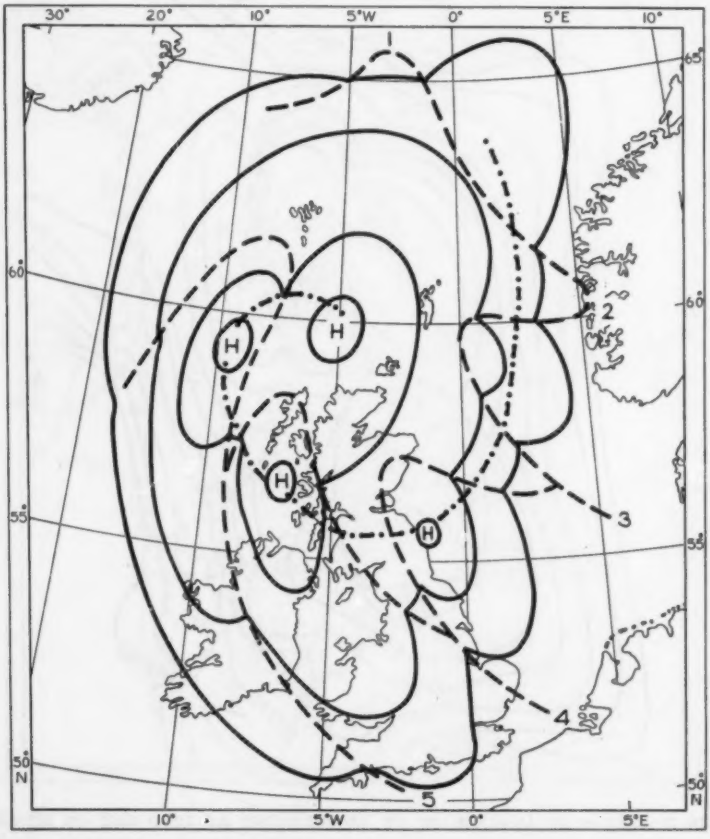

FIGURE 3—SCHEMATIC DIAGRAM OF AN ANTICYCLONE COMPOSED OF A CLUSTER OF CELLS

——— Isobars (schematic) — — — Trough lines
—·—·— Trajectory of an anticyclone cell

familiarity with the types of analyses shown in Figures 1 and 2 may lead eventually to the recognition of some associations between them and other weather elements. At the least a detailed analysis of the topography of surface pressures in anticyclones is a good starting point for detailed local forecasting.

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551.586:612.59(595)

INDICES OF COMFORT THROUGHOUT MALAYSIA

By P. R. WYCHERLEY, Ph.D.
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Summary.—The effective temperatures for lightly clad persons have been calculated as indices of comfort for stations throughout Malaysia. In the majority of cases the minimum is in January and the maximum is in May. The effective temperature declines with exposure, in particular with altitude and close proximity to the coast.

Introduction.—Stephenson[1] has described the calculation of the 'effective temperature' as an 'index of comfort' for Singapore from the mean dry- and wet-bulb temperatures and mean wind speeds for each month, using the nomogram for normal effective temperature appropriate to lightly clad persons.[2] McLeod[3] used the same method to calculate an 'index of comfort' for Gan. They concluded that the effective temperature, which took account of air movement, was a better index of comfort than either dry- or wet-bulb temperatures alone, or relative humidity alone or combined with temperature.

Object.—Various phenological phenomena of plants and aspects of animal behaviour are seasonal ; leaf fall in the Para rubber tree (*Hevea brasiliensis*) and the migrations of birds are examples. However, although the responses by plants and animals are presumably stimulated by some meteorological condition, it is frequently difficult to establish a correlation with any simple parameter such as relative humidity or temperature in an equatorial region, where variations are often small.

The monthly means of the usual meteorological observations and certain calculated values based on similar five-year periods have been compared for the principal stations in Malaysia and Singapore, in order to explore which of them might be of importance in biological sequences. This account discusses variation in effective temperature throughout Malaysia, in view of the interest created by the index of comfort for Singapore, but application to other seasonal phenomena is not attempted in this preliminary report.

Method.—The monthly means of the temperature (24 hours), relative humidity and scalar wind speed were obtained from the *Summary of Observations*[4] during 1957–61 inclusive for Singapore, 10 West Malaysian* stations and 4 stations in East Malaysia and for 8 other West Malaysian stations during 1931 and 1933–36 (these last-mentioned stations did not record wind speed during 1957–61). The wet-bulb temperature was calculated for each month from the air temperature and relative humidity. Since the height of anemometer head above ground level varied among stations, an appropriate correction factor based on Hellman's logarithmic formula was applied in each case to estimate the wind speed at 2 metres above ground level. Apart from

*West Malaysia is also known as Malaya. East Malaysia comprises Sarawak and Sabah.

TABLE I—MONTHLY MEANS OF EFFECTIVE TEMPERATURE

Station	Longitude north	Latitude east	Height above MSL	J	F	M	A	M	J	J	A	S	O	N	D	Annual means	Range
			feet	*effective temperature in degrees Fahrenheit*													
Alor Star	6°12′	100°25′	15	74·0	75·6	77·0	78·0	78·4	77·8	77·0	76·8	76·6	76·8	75·8	74·8	76·6	4·4
Kota Bharu	6°10′	102°17′	15	71·2	72·0	74·6	76·0	77·4	76·6	75·4	75·0	74·4	75·0	73·2	72·2	74·4	6·2
Kuala Trengganu	5°20′	103°08′	105	70·8	72·0	73·8	75·4	76·2	75·2	75·0	74·6	74·2	74·2	73·2	71·4	73·8	5·4
Penang	5°18′	100°16′	11	73·0	74·6	75·6	77·0	77·2	76·4	75·4	75·2	75·0	74·8	74·2	73·2	75·1	4·2
Ipoh	4°34′	101°06′	127	73·2	73·6	74·0	74·6	75·4	75·4	74·0	74·2	73·4	73·2	73·2	73·4	74·0	2·2
Sitiawan	4°13′	100°42′	23	75·0	75·4	75·8	76·4	76·8	76·8	75·2	75·2	75·2	75·0	75·2	75·4	75·6	1·8
Kuantan	3°46′	103°12′	62	69·8	71·0	73·6	75·4	76·2	75·8	74·8	74·8	74·2	74·2	73·2	71·2	73·7	6·4
Kuala Lumpur	3°07′	101°42′	111	75·2	75·6	76·6	76·8	77·4	76·6	75·8	75·2	75·2	75·4	74·8	75·4	75·8	2·6
Mersing	2°27′	103°50′	146	67·4	69·2	71·4	73·6	73·4	72·2	71·4	71·0	70·8	71·4	70·4	68·8	70·9	6·2
Malacca	2°16′	102°15′	22	70·8	72·2	74·2	75·4	76·2	75·2	74·6	74·2	74·2	74·4	73·2	71·4	73·8	5·4
Singapore	1°21′	103°54′	25	72·4	74·0	75·4	77·2	77·6	77·2	76·4	75·6	75·8	76·2	75·6	74·4	75·7	5·2
Butterworth	5°25′	100°22′	6	72·2	72·8	74·0	74·4	75·0	73·8	73·0	72·8	72·8	72·4	72·4	72·2	73·2	2·8
Cameron Highlands	4°28′	101°23′	5120	52·4	53·4	55·2	57·0	55·8	54·4	53·0	54·0	53·4	54·2	54·4	53·4	54·2	4·6
Kuala Lipis	4°11′	102°03′	555	72·8	73·8	74·6	74·8	75·2	74·8	74·8	74·4	74·0	74·2	73·6	72·6	74·1	2·6
Fraser's Hill	3°43′	101°44′	4268	50·6	54·4	57·0	59·6	57·6	57·2	55·2	54·4	54·6	55·0	55·0	53·2	55·3	9·0
Kuala Pahang	3°32′	103°28′	10	68·0	69·6	71·2	73·4	74·0	73·0	72·4	72·2	72·2	72·4	71·0	69·4	71·6	6·0
Temerloh	3°27′	102°26′	165	73·0	74·2	75·2	76·0	76·4	75·4	75·0	74·8	75·0	74·6	74·4	73·6	74·8	3·4
Bukit Jeram	3°15′	101°18′	196	70·4	71·6	71·4	72·0	72·4	71·8	71·4	70·8	71·0	70·0	69·8	69·6	71·0	2·8
Kluang	2°01′	103°19′	215	68·4	69·2	71·4	73·2	74·0	73·0	72·6	72·0	72·4	72·4	71·8	70·2	71·7	5·6
Sandakan	5°54′	118°04′	39	72·4	72·6	74·2	75·4	77·4	77·0	76·6	76·6	76·2	75·6	75·0	74·4	75·3	5·0
Jesselton	5°51′	116°03′	7	72.0	72·2	73·0	73·8	73·6	73·0	72·4	72·6	72·0	72·2	72·4	73·2	72·7	1·8
Labuan	5°18′	115°15′	98	72·8	72·4	75·0	76·2	76·2	75·6	75·4	74·8	74·2	74·4	74·4	74·8	74·7	3·8
Kuching	1°29′	110°20′	84	73·2	74·0	75·0	74·8	76·0	75·6	75·0	75·2	74·0	74·4	74·2	74·8	74·7	2·8

Note : figures for the first 11 and the last 4 stations are based on data for 1957–61 while the remainder are based on data for 1931 and 1933–36.

improving the comparison between stations, this correction to 2 metres may give a more realistic figure for the comfort of human beings (2 metres was selected because it is the height used in Penman type calculations of potential evaporation). The summaries give the wind speeds for 1957–61 in metres per second, but the earlier records for 8 stations are in hours duration of wind-speed ranges corresponding to paired strengths on the Beaufort Scale. A weighting method has given reasonable estimates of the mean wind speed in these cases, which are similar to those by direct calculation where this comparison is possible.

The mean temperature, the calculated mean wet-bulb temperature and the estimated mean scalar wind speed at 2 metres above ground were used to determine the effective temperature by the normal scale nomogram for lightly clad persons. The effective temperature was calculated for each of the 60 months at each station, the 5 representatives of each calendar month were averaged.

Results.—The monthly means of the effective temperature and the range over the 12 months are given in Table I in degrees Fahrenheit. From the top of Table I are, in order from north to south, the 10 West Malaysian stations and Singapore (observations for the years 1957–61), next are the 8 West Malaysian stations (observations for the years 1931, 1933–36), and finally the 4 stations in East Malaysia (observations for the years 1957–61).

The pattern of variation throughout the year is essentially the same at all stations. There is a cycle from low, about or usually just after the northern winter solstice, to high before the summer solstice. The minima fall in the period September to February, although rarely occurring in the first or last of these months ; the minimum is in January at 19 of the 23 stations, including 4 where this distinction is shared with other months. The maxima are restricted to the period April to June, occurring in May at 19 of the 23 stations, including 3 where the same maximum is attained in another month also. This pattern does not seem to be affected by such features as exposure to the north-east monsoon.

The classification adopted by the earlier authors recognized the following categories :

Comfort range	Effective temperature *degrees Fahrenheit*
Above acceptable	above 76
Upper acceptable	73 – 76
Optimum	69 – 73
Lower acceptable	66 – 69
Below acceptable	below 66

The two hill stations, Cameron Highlands and Fraser's Hill, are continuously well below the lower acceptable range. However, people are not so lightly clad in the hills as in the lowlands and holiday makers go there to enjoy the cool climate with fires in the evening. The lowland stations may be ranked in ascending order of mean annual effective temperature or by scoring for the number of months in each category of the classification. Both methods of ranking agree. The rather high proportion of favourable stations among those for which the older records were used, might suggest an error in the method of wind speed estimation. However, detailed inspection shows that the results are consistent with local circumstances and in comparison with the others.

For instance the most favourable stations in the two period series are Mersing and Bukit Jeram; both are sited on small hills close to the sea, enjoying frequent breezes. The old-fashioned bungalows with wide verandahs and tall rooms built on such sites are acknowledged to be very comfortable.

The following have a majority of months in the optimum range : Bukit Jeram, Butterworth, Jesselton, Kluang, Kuala Pahang and Mersing. Excepting Alor Star, at which most months are above the acceptable range, and the two cool hill stations, all the rest have the majority of months in the upper acceptable range ; Kuala Lipis, Kuala Trengganu, Kuantan and Malacca have more months in the optimum range than in the above-acceptable range while Labuan and Kota Bharu have equal numbers of months in these ranges.

Discussion.—The annual mean effective temperature is much lower in the hills, but owing to the lack of intermediate stations it is not possible to determine the variation with altitude in detail; the decline in annual mean effective temperature seems to be about 4 degF for every 1000 ft increase in altitude. On this basis the annual means have been corrected to sea level ; they then show an increase with distance inland. The rate of increase appears to be rapid close to the coast and then to fall off further inland. Plotting the logarithm of effective temperature corrected to sea level against the logarithm of the distance inland gave the best fit. Even so some stations situated near the centre of West Malaysia had rather low means even when corrected to sea level; perhaps these places receive influences from both coasts. The increase in mean annual effective temperature relative to that at one mile inland is given in Table II according to the best-fitted curves, (*a*) based on 23 stations and (*b*) based on 18 stations, omitting 5 anomalous central stations.

TABLE II—AVERAGE INCREASE INLAND OF THE MEAN EFFECTIVE TEMPERATURE ABOVE THAT AT 1 MILE INLAND

	Distance inland (miles)					
	1	2	5	10	20	50
	degrees Fahrenheit					
(*a*) based on 23 stations	0·0	0·3	0·8	1·2	1·8	2·3
(*b*) based on 18 stations	0·0	0·5	1·4	2·1	3·0	–

The annual means can be adjusted further for distance inland as well as height above sea level. However, whichever of the above relationships in Table II is used or if no further adjustment is made, no other significant relationships can be established, although there is a slight tendency for effective temperatures to be higher further north.

Mean air temperatures tend to increase northward and inland in West Malaysia and to decline with elevation.[5] The trend in relation to latitude is not marked for effective temperature, but its decline with proximity to the coast or with altitude is very evident, presumably due to the influence of the winds which are stronger near the coast or in the hills.[6] Local topography and exposure probably have a considerable effect and may account for the residual variation.

The range in monthly means of the effective temperature is not clearly correlated with any feature. Most of the stations where the range is small are sheltered, but there are exceptions such as Bukit Jeram, Butterworth and Jesselton, which are relatively exposed and the wind blows moderately strongly and constantly throughout the year. Certainly variation in wind speed throughout the year has a considerable effect on the effective temperature range.

Conclusions.—

(i) The pattern of variation in effective temperature through the year is similar at all stations in Malaysia and Singapore for which records are available. In the majority of cases the minimum is in January and the maximum is in May.

(ii) Apart from the hill stations, which are cool throughout the year, there is a range from exposed low hill sites near the coast where the effective temperature is in the optimum range for comfort throughout the year, to the northern coastal plain where for two-thirds of the year the effective temperature exceeds the acceptable range for comfort.

(iii) The effective temperature declines with altitude and with close proximity to the coast. Exposure to breezes is probably the most important factor in obtaining the optimum range for comfort in the lowlands. This is in accord with experience.

Acknowledgements.—The permission of the Director of the Rubber Research Institute of Malaya to publish this account is gratefully acknowledged. Special thanks are due to Miss Loke Yin Ho for computing the effective temperatures.

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551.575.36(425):551.591.36

A COMPARISON OF THE INCIDENCE OF FOG AT A COASTAL STATION WITH THAT AT AN INLAND STATION

By F. J. SMITH

It is well known to forecasters that there is a marked decrease in the frequency of fog, and in the smoke content, to the east of the Lincolnshire Wolds, as compared with further inland. This note compares the frequency of fog and thick fog at a coastal station (Strubby) with that at an inland station (Syerston) (see Figure 1).

Strubby (47 feet above mean sea level) is 4 nautical miles inland, near the western edge of the coastal plain. The plain comprises flat fenland with numerous dykes. To the west of Strubby the ground rises within 4 n.miles to 300–400 feet above MSL. There are no large smoke sources within 15 n.miles.

Syerston (224 feet above MSL) is in the Trent valley, on a low ridge to the south of the river. It borders on a large industrial and mining area and is only 11 n.miles from the centre of Nottingham.

The meteorological observing commitments for the two stations are identical. Both make hourly observations from Mondays to Fridays from 0000 to 1700 GMT in winter and 0000 to 1600 GMT in summer. Their records are therefore fully comparable and the period covered by regular observations is sufficient to demonstrate the differences between them.

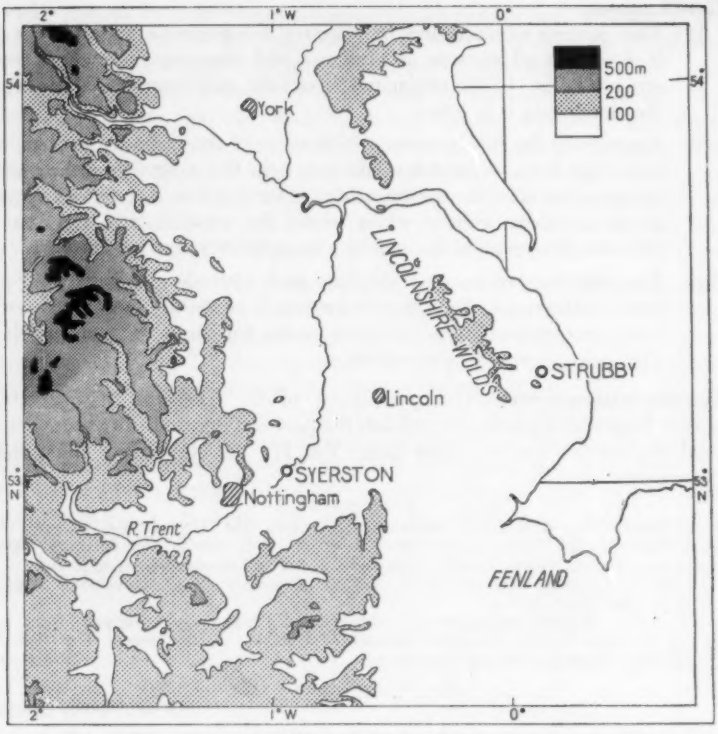

FIGURE 1—POSITIONS OF AERODROMES USED IN THE INVESTIGATION

In Figures 2 and 3 the percentage frequencies of fog (visibility less than 1100 yards) and thick fog (visibility less than 220 yards) are shown side by side for ease of comparison. These diagrams cover the period 1956–64.

The following points are noteworthy :

Figure 2

(i) The patterns are basically similar in shape.

(ii) At most times during the winter half-year fog is 2 to 2½ times as frequent at Syerston as at Strubby.

(iii) Only in January is fog frequency greater than 5 per cent thoughout the day at Strubby, whereas at Syerston it is greater than 10 per cent throughout the day in November, December and January.

(iv) During summer, fog frequencies from midnight to two or three hours after dawn vary less at Strubby than at Syerston. At Syerston the fogs that occur during summer form mostly around dawn ; until an hour or two before dawn the frequency of fog is less than 1 per cent.

(v) There is a rapid increase in fog frequency at both stations in the autumn with the annual maximum frequency occurring in October around sunrise.

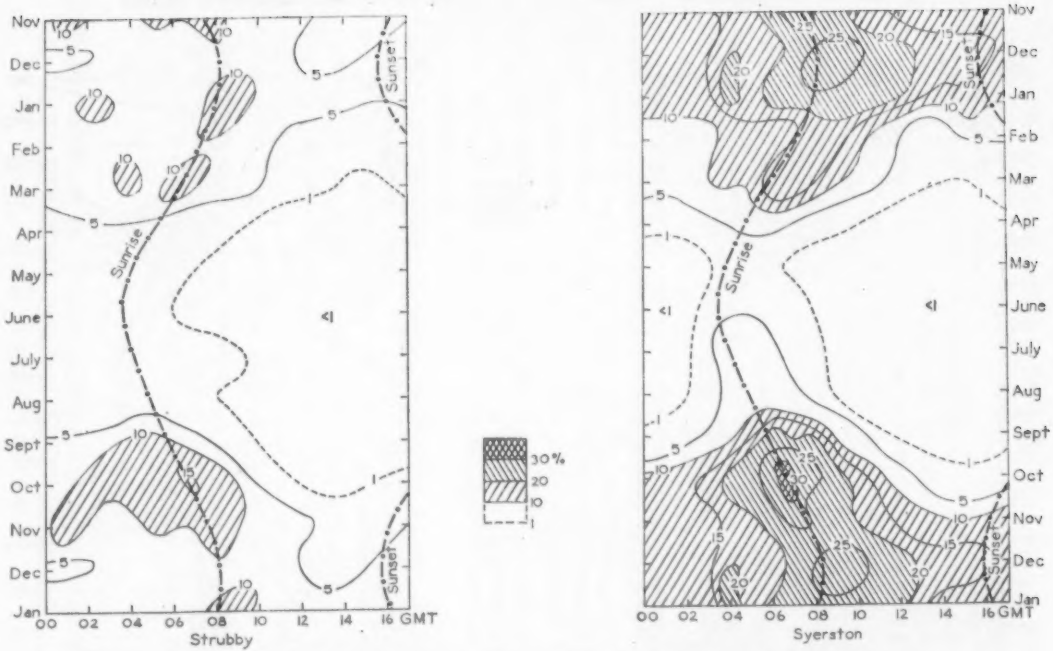

FIGURE 2—PERCENTAGE FREQUENCY OF FOG AT STRUBBY AND SYERSTON

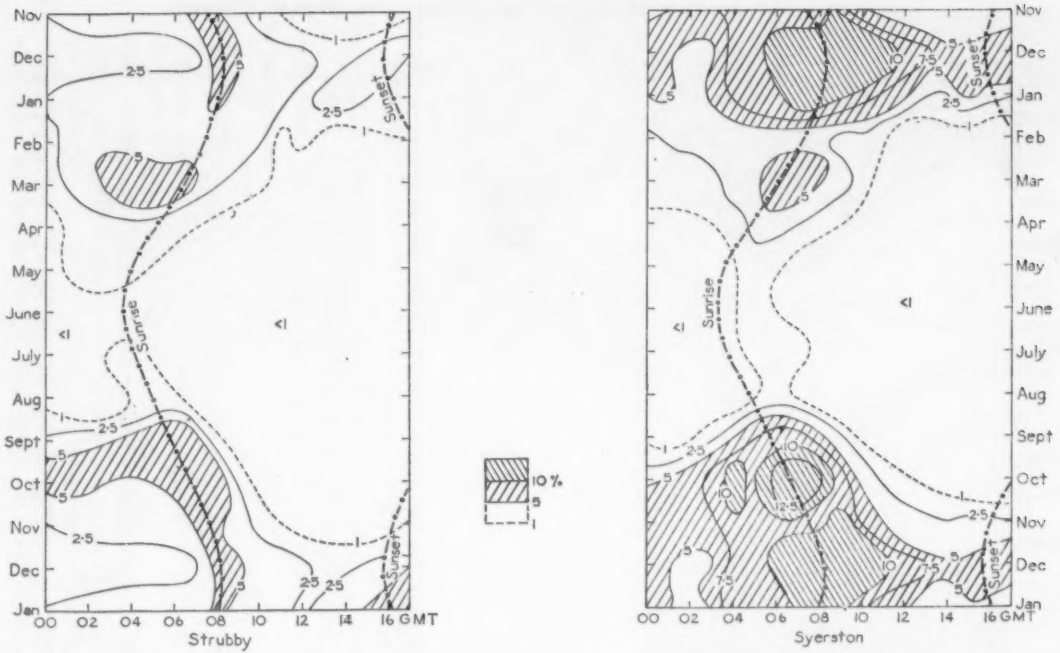

FIGURE 3—PERCENTAGE FREQUENCY OF THICK FOG AT STRUBBY AND SYERSTON

Figure 3

(i) Although the patterns are similar, the two diagrams for thick fog do not show the same general agreement as the diagrams for fog.

(ii) At most times during the winter half-year thick fog is 2 to 2½ times as frequent at Syerston as at Strubby.

(iii) There is a low frequency of thick fog in the night hours at Strubby in December and a drop in frequency from 0000 to 0300 GMT at Syerston in December and January.

(iv) There is a rapid increase in frequency in autumn. The annual maximum frequency is reached at Syerston in October around sunrise. The peak is less obvious at Strubby and is an extension of a high frequency in the early hours which does not occur at Syerston.

(v) In December and January frequency falls below 2·5 per cent for one to two hours in the early afternoon at Strubby, but remains greater than 5 per cent at Syerston in December.

General comments.—In quiet winter conditions the weather at Strubby and the adjacent areas is often relatively clear and sunny, whilst on the other side of the Lincolnshire Wolds widespread thick (sometimes freezing) fog occurs by day and by night. The present analysis includes all reports of visibility below 1100 yards and below 220 yards and is therefore not purely confined to the quiet winter conditions mentioned. Even so, the increase in frequency of both fog and thick fog at Syerston in the autumn and winter is very marked in the diagrams. It is considered by local forecasters that the figures for Syerston are broadly representative of places to the west of the Lincolnshire Wolds.

It is noted that despite the nearness of Strubby to the coast and a relatively cold sea surface in the summer months, the incidence of fog during most daylight hours is less than 1 per cent. (Surface heating will lift most sea fog into low stratus or burn it off altogether.)

The slightly higher frequency in summer at Strubby referred to in note (iv) under Figure 2 is due to advection over land during the afternoon and evening of moist sea air with a higher fog-point than that applicable further inland.

The relatively low frequency at night at Syerston mentioned in note (iii) under Figure 3 is probably partly related to the diurnal decrease in the smoke content during the night, but it has also been noted at Strubby that fog often thins out during the early hours before thickening again at sunrise.

Acknowledgements.—Acknowledgement is made to the Meteorological Officer, Syerston, and his staff and to the staff at the Meteorological Office, Strubby, for their help in compiling the tabulated data on which these diagrams and this note are based.

551.510.721:551.594.11

THE INFLUENCE OF RADIOACTIVE FALLOUT ON THE ATMOSPHERIC POTENTIAL GRADIENT

By R. A. HAMILTON and J. G. PAREN

Introduction.—The effect of nuclear explosions on the atmosphere has in general been local and short-lived but they have caused a remarkable change in the atmospheric electrical potential gradient near the ground which has persisted for some years—at a number of places fair-weather potential gradient in 1959 and in 1963 was only about one-third of its pre-1950 value.

The main cause of the change appears to be the increased ionization in the air produced by β-rays from radioactive products of the nuclear explosions which are brought down by rain from the upper atmosphere and deposited on the ground.

The rate of ionization of the air near the ground is quoted by Chalmers[1] as being about 11 *I* (11 ion pairs per cm^3/s), of which about 2 *I* are produced by cosmic rays, about 4 *I* by natural radioactive material in the ground, and about 5 *I* by radioactive material in the air. At higher levels ions are produced only by cosmic rays and these increase rapidly with height—almost all the ions in the atmosphere are produced by cosmic rays. Ions can be regarded as the carriers of the fair-weather air–earth current, and if their rate of production is unchanged and the potential between the earth's surface and the upper conductive layers of the atmosphere remains unchanged, there will be no change in the fair-weather air–earth current. Thus an increase in the conductivity of the lowest metre of the air, due to increased ionization by β-rays from the ground, would result in a proportionate decrease in the potential gradient in the lowest metre of air.

Stewart[2] measured the rate of ionization of the air, about 10 cm above the surface, by β-rays from the ground at Eskdalemuir (55° 19′N, 3° 12′W) and Lerwick (60° 08′N, 1° 11′W) in 1959 and obtained values some two to three times the expected values of 4 *I*. (Measurements were also made at Kew (51° 28′N, 0° 19′W), but as it is not possible to distinguish between the effect of changes of pollution and changes of β-ray activity the Kew results will not be discussed.) It was decided to repeat Stewart's measurements, using his apparatus, at Lerwick and Eskdalemuir in the summer of 1964, when the radioactivity on the ground resulting from the extensive 1962 weapon testing was expected to be very high, though past its maximum.

Measurements of ionization.—Briefly the apparatus consists of two ionization chambers 28 × 28 × 7½ cm, the sides and tops of which are opaque to β-rays, but the bottoms consist of thin aluminium foil almost transparent to β-rays but opaque to α-rays. Thick aluminium shields are normally held in position below the bottoms of the chambers. The inner electrodes of the chambers are connected together to a Lindemann electrometer while the chambers are kept at equal and opposite potential so that ionization currents produced in the chambers, by airborne radioactivity and cosmic rays, are in opposite idrections and thus have no effect on the electrometer. Removing the shield from one chamber causes a positive current to the electrometer : this is measured and then the negative current is measured when the other chamber is exposed. In this way the effects of electrometer drift and of stray ionization currents are eliminated. The first Lerwick results showed very high ionization values, some three times the 1959 values, and some ten times the supposed pre-1950 values.

It was soon found that it was not easy to make accurate measurements with the apparatus in the open in the windy climate of Lerwick, and it was more convenient and accurate to cut out a sod of earth with the same cross-section as the chamber, and about 8 cm thick, and place it under the apparatus in the laboratory. By measuring the activity of such a 'turf' cut from soil, which had previously been measured in the normal way, the factor 1·26 by which the turf activity must be multiplied in order to obtain the infinite plane activity

which would be measured outside was obtained. This technique enabled measurement to be made of the β-ray activity of other sources, e.g. peat from deep in the ground, pieces of rock, rainwater—all of which showed no measurable activity.

Energy of the β-rays.—In order to be able to interpret the ionization chamber measurements, and to deduce the rate of ionization in the lowest metre of the atmosphere—for routine measurements are made of the potential between a height of 1 m and the surface—it is necessary to know something about the energy of the β-rays, the half-lives of the radionuclides, and the rate of penetration of the latter into the soil.

The radioactivity of samples of Lerwick soil was examined with a Geiger counter. Transmission experiments were performed, i.e. aluminium absorbers were placed over the samples and the reduction in counting rate led to an evaluation of the energy of the β-rays. Because the sample contributed less than background, only a very long counting time could give the energy of the constituent radionuclides. It was only possible to identify β-rays of energy 3 mega electron-volts (MeV) with any degree of certainty : energies of about 1·4 MeV appeared to be present also, but it was not possible to determine whether there were β-rays of this energy or whether there was a mixture of higher and lower energies. (Here, conventionally, the maximum energy of the β-ray spectrum is quoted.)

An analysis made at Harwell of the Lerwick rainfall for August 1964 showed that the main β-ray emitters were $^{144}_{59}$Pr (2·98 MeV) and $^{144}_{58}$Ce (0·32 MeV). Forty-four per cent of the β-rays had energies of about 3·0 MeV and 40 per cent had energies in the range 0·25 to 0·65 MeV. Consideration of what would be the result of a transmission experiment on a sample containing radionuclides in the same proportion as found in the rainwater gave counting rates which agreed, within the rather large limits of statistical error, with the counter experiments with the Lerwick soil. For simplicity it is assumed that the β-rays have energies 0·35 and 3·0 MeV (ranges in air of 100 and 1200 cm respectively) in equal proportion.

Weathering of radionuclides.—The ionization by these radionuclides decreases not only on account of their radioactive decay but also because they penetrate slowly into the soil.

Gale et alii[3] measured the rate of penetration into various types of soil of radioactive material placed on the surface. After 5 years the concentration was found to decrease approximately exponentially with depth, with a half-depth, i.e. the depth at which the concentration was one half of that at the surface, of about 3 cm.

From the measurements at Lerwick of the activity of a turf, of the inverted turf, and of the soil below the turf, it was deduced that the half-depth of the radionuclide was about 1 cm.

The half-life of the parent radionuclide $^{144}_{58}$Ce is 285 days : it is clear that the ionization activity will decrease quite quickly because of decay of the active material and its penetration into the soil.

Exposure factor.—The β-rays will cause less ionization in the ionization chamber than they would in an equal volume of air, for the side walls will stop β-rays originating from places not immediately below the chamber and

which would otherwise have ionized the air in the chamber. The measured ionization must, therefore, be multiplied by an exposure factor to obtain the rate of ionization in the air. It is clear that the exposure factor will depend on the energy of the β-rays and the half-depth of penetration : using the values given above, a value of 1·63 was deduced for the factor. Stewart used the value 1·33, and in this account his published ionization rates have been multiplied by the factor 1·22.

Variation of ionization with height.—β-rays emitted from radioactive material on the surface will cause maximum ionization, but those from below the surface will emerge with reduced energy ; about 0·5 mm of soil is sufficient to stop β-rays of energy 0·35 MeV and 6 mm will stop 3-MeV β-rays. It is clear that the rate of ionization will decrease with height, and will depend on the energies of the β-rays and the half-depth of penetration. Using the values given above, it is deduced that the rate of ionization decreases to a value at 1 m of 0·62 the rate at 10 cm. Stewart measured the rate of ionization at 60 and 160 cm and obtained values of 0·78 and 0·27 of the rate at 10 cm. From all these results it is concluded that the average rate from surface to 1 m is 0·8 of the 10-cm value.

Measurements at Lerwick.—Ionization varied from place to place being generally 40 to 50 *I* at 10 cm above natural peat surfaces and about 20 *I* in areas which had recently been dug, and, in the meteorological enclosure, lightened by the admixture of sand. Most of the surrounding soil is peat and, though the covering of heather must cause some absorption of β-rays, it is estimated that the average ionization rate is 40 *I* with a mean rate of about 32 *I* from surface to 1 m.

Measurements at Eskdalemuir.—The activity of three turfs was measured at Eskdalemuir in September 1964—the values, before drying, were 38, 35 and 43 *I*—and a mean value of 31 *I* from surface to 1 m is accepted.

Correlation of potential gradient with ionization rate.—When we attempt to correlate the rate of ionization, assuming a contribution of 7 *I* from cosmic rays and radioactive material in the air, with the potential gradient, we find no close correlation, as is shown in Table I.

TABLE I—THE RATE OF IONIZATION IN THE LOWEST METRE AND REPRESENTATIVE POTENTIAL GRADIENTS FOR EXPERIMENTS IN THE YEARS 1950, 1959 AND 1964

	Potential gradient (*PG*) *V/m*	Total rate of ionization (*I*) *ion pairs per cm³/s*	Product of *PG* and *I*
Lerwick 1950	200	11	2200
Eskdalemuir 1950	200	11	2200
Lerwick 1959	110	16	1760
Eskdalemuir 1959	50	20	1000
Lerwick 1964	110	39	4290
Eskdalemuir 1964	100	38	3800

It should be pointed out that the potential gradient is a quantity, which varies with cloud type and height, wind, atmospheric pollution, etc. and it is difficult to normalize it : this has been discussed by Hamilton.[4,5] The figures quoted in the table represent the general level of potential gradient on an undisturbed day and cannot be stated with accuracy ; the values in the table have been derived by perusal of the *Observatories' Year Book*.[6] Nevertheless,

without any doubt the potential gradient at Eskdalemuir in 1959 was extremely low, and the ionization rates seem very low compared with the 1964 values. The effect of rain is difficult to assess : it was found at Eskdalemuir that thorough drying of turfs increased the ionization by a quarter : the mean potential gradient will have been averaged over all states of wetness of the ground, while the ionization measurements may have been made in conditions somewhat drier than the average—but the effect of this is probably small.

It is clear that in using a saturated ion chamber to determine the ionization of the air one is measuring the rate of production of ions. The concentration of small ions in the lowest metre of the atmosphere (it is this which would vary inversely as the potential gradient for constant current) depends not only on the rate of ionization but also on the rate at which the ions are carried upwards by convection or diffusion, and on the mean-life of an ion before it attaches itself to a nucleus or recombines. The concentration does not necessarily vary directly with the rate of ionization. This could account for the increase of ionization being greater than the decrease of potential gradient in 1964, but cannot explain the very low potential gradient in 1959 with only small increase in ionization. There is clearly scope for more research in this field, and it is desirable that the air–earth current should be measured as well as the potential gradient ; such measurements are made occasionally at Kew and are published in the *Observatories' Year Book*. It is now proposed to make continuous recordings at Kew, Eskdalemuir and Lerwick.

Acknowledgements.—The authors would like to thank Mr R. S. Cambray, Atomic Energy Research Establishment, Harwell, for advice and criticism, the staff of Eskdalemuir Observatory for making the observations there, and Dr P. S. Farago of Edinburgh University for permitting Mr Paren to carry out the laboratory investigation.

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FURTHER TESTS OF THUNDERSTORM FORECASTING TECHNIQUES

By W. E. SAUNDERS

Tests of thunderstorm forecasting methods carried out at meteorological offices under the author's control in 1965 were described in an earlier paper.[1] This note gives a brief account of further tests in 1966. Tests for the Manby Group area were carried out in exactly the same manner as in 1965, but the methods tested were varied.

In the Hanssen method,[2] an additional diagram was included for use with troughs or ridges to east of the area. In both the modified Jefferson[3] and Boyden[4] methods, some doubt had arisen concerning the best critical values,

TABLE I—ACCURACY OF THUNDERSTORM FORECASTS FOR AN AREA

Method*	Testing station	Accuracy of forecasts of occurrence/non-occurrence: Number of forecasts	Number correct	Percentage correct	Accuracy of forecasts of occurrence: Number of forecasts	Number correct	Percentage correct	Accuracy of forecasts of non-occurrence: Number of forecasts	Number correct	Percentage correct	Skill score: 1966	1965
'General practice'	Manby	126	111	88	45	35	78	81	76	94	0·73	0·54
Boyden 94/95	Leeming	122	101	83	41	30	73	81	71	88	0·61	–
Rackliff 29/30	Syerston	122	100	82	35	26	74	87	74	85	0·57	0·46
Jefferson 27/28	Oakington	124	98	79	38	26	68	86	72	84	0·51	0·36
Jefferson 26/27	Oakington	124	95	77	49	30	61	75	65	87	0·49	–
Boyden 93/94	Topcliffe	124	93	75	51	30	59	73	63	86	0·47	0·40
Hanssen	Manby	125	88	70	51	27	53	74	61	82	0·37	0·40
Jefferson 25/26	Strubby	125	87	70	57	29	51	68	58	85	0·37	–

* Critical values shown where applicable.

TABLE II—ACCURACY OF THUNDERSTORM FORECASTS AT LEEMING AIRFIELD

Method*	Testing station	Accuracy of forecasts of occurrence/non-occurrence: Number of forecasts	Number correct	Percentage correct	Accuracy of forecasts of occurrence: Number of forecasts	Number correct	Percentage correct	Accuracy of forecasts of non-occurrence: Number of forecasts	Number correct	Percentage correct	Skill score
'General practice'	Linton-on-Ouse	122	115	94	12	7	58	110	108	98	0·64
Jefferson 27/28	Church Fenton	126	112	89	21	8	38	105	104	99	0·48
Rackliff 29/30	Acklington	132	119	90	18	7	39	114	112	98	0·47
Jefferson 26/27	Church Fenton	126	110	87	25	9	36	101	101	100	0·47
Boyden 93/94	Topcliffe	126	109	87	24	8	33	102	101	99	0·43
Boyden 94/95	Leeming	122	103	84	24	7	29	98	96	98	0·36
Jefferson 25/26	Linton-on-Ouse	122	99	81	28	7	25	94	92	98	0·30
Jefferson 24/25	Linton-on-Ouse	122	87	71	42	8	19	80	79	99	0·22

* Critical values shown where applicable.

following the work of Lowndes.[5,6,7] Furthermore, in unpublished tests carried out by Uxbridge for an area covering southern England, the best critical values using the Boyden method had been found to be 94/95. The higher number represents the minimum index for forecasting the occurrence of thunderstorms while the lower value is the maximum used for forecasting non-occurrence.

It was also desired to test a suggestion by Jefferson[8] that in his index the more easily available 850 mb wet-bulb potential temperature could be used in place of the 900 mb value.

The remaining method included was that of Rackliff.[9]

As in 1965, the results obtained when the forecaster was free to use any method were included under 'general practice'.

The results obtained from the Manby Group area are given in Table I. When a method using the same critical value was also included in the 1965 tests, the skill scores obtained in that year are included under '1965' for ease of comparison. The skill score, S, is defined[10] by

$$S = \frac{\text{number of correct forecasts} - \text{number correct by chance}}{\text{total number of forecasts} - \text{number correct by chance}}.$$

It ranges from 0 for no success to 1 for complete accuracy.

The skill scores take account of all the forecasts. A method may however be very successful in that it forecasts a high proportion of the thunderstorms which occur, but at the expense of being unsuccessful with forecasts of non-occurrences. The user of a forecast may have a preference for a method which ensures, for example, that most thunderstorms are forecast, although such a method may give many false warnings. The detailed results[11] of the tests show that there can be circumstances in which the method to be preferred may not be the one with the highest skill score. The number of occasions are thought to be insufficient to indicate conclusively the preferred methods.

The forecasts by 'general practice' have proved superior to forecasts restricted to a particular method. It is difficult to assess all the background knowledge which was used in 'general practice'. It is certain that a detailed study was made of all relevant tephigrams on each occasion. Allowance was also made for advective changes of temperature and humidity, the wind field at various levels, subsidence and estimates of the likely depth of convection cloud. The 'general practice' forecast thus used more parameters and paid attention to the individual circumstances as well as to statistical results.

Tests of 'yes' or 'no' thunderstorm forecasts for small areas were included. The 'small areas' were taken as individual aerodromes, and the tests marked against the station records. The results for Leeming, an inland station, are given in Table II. The skill scores are lower than those given in Table I for the Manby Group area. 'General practice' gave the best results, probably mainly because forecasters were able to keep in mind that the probability of a thunderstorm at a given spot is substantially less than for a given large area. For convenience the objective methods had to use the same threshold value for a spot as for the area, whereas the threshold value calculated specially for a spot would be higher than that used for an area. For small areas it would seem reasonable to adopt a slightly higher threshold value for an objective instability index method.

Tests for the aerodrome at Manby, which is very near the coast, produced even lower skill scores, by all methods.

It was found practicable to divide the test days into three groups according to air mass : (i) polar maritime (ii) returning polar maritime and (iii) warm and miscellaneous air masses. Most of the thunderstorms occurred in groups (i) and (ii), particularly (ii). The Rackliff method which was designed for use in convection conditions shows to advantage in group (i).

The main conclusions reached following these tests were as follows :

(i) The Boyden index appears to be the most useful forecasting aid for area forecasting in eastern England in summer, and 94/95 the best critical value for area forecasting. The more detailed report[11] shows that in some special circumstances another method may produce better results, e.g. Rackliff in polar maritime air mass.

(ii) With the modified Jefferson method, use of the 850 mb wet-bulb potential temperature appeared to have no adverse effect, in that the skill score showed a good increase over that obtained in 1965. However, one station commented that there were often inversions below 850 mb, and considered that it would be better to revert to 900 mb. The time taken to calculate the index was 30 seconds per ascent used.

(iii) In forecasting for small areas, better results were obtained for inland locations than for those near the coast. In this work there seems little to choose between the various methods tested, though 'general practice' gave the best results. The objective methods may be improved by adopting a slightly higher threshold value than for area forecasting.

(iv) Comparison of the skill scores obtained in 1965 and 1966 in Table I shows that better results were obtained in the latter year using 'general practice' and also in all those individual methods which require the skill and judgement of the forecaster. This might in part be due to the fact that there were fewer actual thunderstorm days (46 in 1965, 40 in 1966). This could account for some improvement, since in these tests there is always a higher proportion of correct 'no' forecasts. However, it leaves a strong impression that repeated testing has its own intrinsic value in making forecasters more aware of the problems involved and raising the general level of experience in dealing with them.

Acknowledgements.—As in 1965, some 40 forecasters have contributed to the results obtained. They have the satisfaction of knowing that their efforts have contributed to an improvement in thunderstorm forecasting.

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551.553.8:519.2

A COMPARISON BETWEEN STATISTICS BASED ON WIND OBSERVATIONS AVERAGED OVER TEN MINUTES, AND OVER ONE HOUR

By B. F. BULMER, M.A., B.Sc.

Summary.—Frequencies of strong winds based on hourly mean values are shown to differ significantly from corresponding frequencies based on synoptic reports taken 'at the hour' and the difference is demonstrated for two stations in England. With stronger winds the discrepancy increases and at gale level the frequency recorded by using synoptic reports may be many times that based on hourly mean values.

Introduction.—An examination of some recent climatological data showed an almost complete absence of gales in a region where previous long-term averages had shown a moderate frequency. This discrepancy was ultimately traced to the fact that the recent data were derived from hourly mean values whereas the earlier data had been based on synoptic reports which give an average wind over a much shorter period which may vary from 10 minutes to 15 seconds according to the instruments available (Observer's Handbook[1]). When comparing the frequency of strong winds or of gales at a number of stations one must base all the wind-speed frequencies on means over intervals of the same duration.

Some previous work.—Durst[2] has discussed the problem of the variation of wind in small intervals of time. He shows that, relative to a given hourly mean wind speed, the maximum mean speed in a smaller interval of time increases as the sampling interval decreases and becomes highest in the brief gusts of the order of a second's duration. In his final table (Table VIII) he gives probable values of the maximum wind speed averaged over short periods of time (including 10 minutes) corresponding with hourly mean wind speeds of 20, 30, 40, etc. miles per hour (m.p.h.). According to this table there is comparatively little discrepancy between the maximum 10-minute values and the corresponding hourly mean values. For an hourly mean speed of 20 m.p.h., the maximum 10-minute speed is 21 m.p.h. and for an hourly mean speed of 40 m.p.h., the maximum 10-minute speed is 43 m.p.h.

Lest these figures might be thought to dispose of the question of the comparison between hourly mean and 10-minute data, let us inspect them more closely. These maximum values which Durst derives are probable maximum values likely to occur once in an hour corresponding to a given hourly mean wind *when there is no general change of wind direction or speed during the (hourly) period.* Thus this comparison differs radically from the one which is now sought, namely, the comparison between the frequencies of a given level of

wind speed recorded on the two contrasting scales (hourly mean and 10-minute) hour by hour, day by day and year by year, irrespective of any limiting condition on variability of wind.

The assumption of a uniform general level of wind is seldom realized in practice. In fact the wind usually contains a great variety of surges and squalls. If all these be taken into account the 10-minute wind on an individual occasion may be very much higher (or lower) than the corresponding hourly mean value and so the frequency of high mean winds (taken over a long period of years) will be greater for a 10-minute wind than for an hourly mean wind. This discrepancy is additional to that arising when the general level of wind is constant.

Shellard[3] has compared maximum hourly mean wind speeds and maximum gust speeds for stations in the United Kingdom, and has also commented[4] on the variation of maximum wind speeds according to the duration of the sampling interval. The present question, namely the variation in frequency of a given (high) speed according to the duration of the sampling interval, although different is closely related. It may perhaps be regarded as a specific example of a more general problem.

Shellard[4] reproduces an anemogram from Tiree from which it can be seen that the mean wind for the 10 minutes ending at 1800 GMT reached about 70 kt while the hourly mean value for the hour ending 1800 was about 40 kt. This is an indication of the sort of discrepancy which can arise between measurements on the two contrasted time scales when all limitations on variability of wind are removed.

Data used.—The present investigation examined statistics of mean winds for durations of 1 hour and of 10 minutes. Attention was restricted to wind observations recorded on pressure-tube anemometers, in order to avoid introducing any complications due to different instrumentation. At the stations chosen both the 10-minute wind at the hour and the corresponding hourly mean wind were taken from the same instrument. The two values, as entered on the Return of Hourly Observations — Form 3257B, were scrutinized hour by hour for each day, month and year for several years, and the number of occasions of (*a*) strong winds (22 kt and above) and (*b*) gales (34 kt and above) was recorded separately from (1) the 10-minute values and (2) the hourly mean values.

Boscombe Down.—The first station investigated was Boscombe Down in Wiltshire. Details of the anemometer exposure are as follows :

Height of anemometer vane above mean sea level — 425 ft
Height of anemometer vane above ground — 55 ft
Effective height — 55 ft from 231° to 049° (through north-west)
Effective height — 30 ft from 050° to 230° (through south-east).

This means that with wind directions between 240° and 040° inclusive (through north-west) a correction has to be applied to the values indicated by the anemograph to reduce them to the standard height (33 ft). The correction applied is a reduction of 10 per cent of the indicated value. No correction is necessary with other wind directions. In the case of the 10-minute wind this correction is applied before the values are entered on the return form (F3257B) but the hourly mean winds are entered without correction. Accordingly, to make the two records fully comparable, the hourly mean values, as entered, were corrected in the same way as had already been done for the 10-minute values.

The number of occasions when the corrected wind speed reached the specified levels on each of the two contrasted scales was noted and annual totals recorded for each of six years. The yearly totals were summed, meaned and the average annual frequencies compared. The figures are given in Table I.

TABLE I — NUMBER OF OCCASIONS OF SPECIFIED WIND SPEEDS AT BOSCOMBE DOWN

Year	10-minute wind		Hourly mean wind	
	22 kt and over	34 kt and over	22 kt and over	34 kt and over
1959	215	2	183	1
1960	188	1	131	0
1961	296	1	234	0
1962	379	9	309	2
1963	164	3	130	0
1964	177	4	163	0
6-year total	1419	20	1150	3
Mean annual number of occasions	236·5	3·33	191·7	0·5

It can be seen that the frequency of strong winds (22 kt and over) derived from the 10-minute values is appreciably greater than that derived from the hourly mean values. The former represents a 23 per cent increase over the latter. When it comes to gale frequencies (34 kt and over) the figure derived from the 10-minute values is six times that derived from the hourly mean values.

Thorney Island.—The second station investigated was Thorney Island, Hampshire, where again the synoptic wind observations and the hourly mean values are read from the same pressure-tube anemograph. Here, the height of the anemometer vane above mean sea level is 75 ft. The effective height of the anemometer is 42 ft so that no corrections are involved.

The records for this station were subjected to the same analysis as that described above for Boscombe Down and the results are in Table II.

TABLE II—NUMBER OF OCCASIONS OF SPECIFIED WIND SPEEDS AT THORNEY ISLAND

Year	10-minute wind		Hourly mean wind	
	22 kt and over	34 kt and over	22 kt and over	34 kt and over
1959	118	3	91	1
1960	82	0	58	0
1961	79	0	60	0
1962	225	3	181	0
1963	108	0	91	0
1964	62	0	59	0
6-year total	674	6	540	1
Mean annual number of occasions	112·3	1	90	0·17

Thus at Thorney Island the average frequency of winds of 22 kt and over is 25 per cent more on the 10-minute scale than on the hourly mean scale, while, at 34 kt, the frequency on the 10-minute scale is six times that on the hourly mean scale.

Discussion.—The fairly close agreement between the results from these two stations does not necessarily mean that the same discrepancies are to be expected at other stations. Where gales are appreciably more frequent than at the two stations considered, one might reasonably expect the ratio between the gale frequencies on the two scales to be lower. However, it would probably be fair to say that for stations in the British Isles where the frequency of strong winds, or gales, is at all similar to that at Boscombe Down or Thorney Island, and where there are no major topographical complications, the discrepancy (ratio) between frequencies at the specified levels, assessed on the two contrasted

scales would be roughly similar to the values quoted. To check this and to establish th discrepancy at stations where gales are more frequent, it would be desirable to make similar comparisons at a number of other stations.

In conclusion it is stressed that statistics of gale frequencies are meaningless unless the duration of the averaging period is specified since, especially where gales are infrequent, frequencies based on 10-minute values can be many times greater than those based on hourly mean values, while frequencies based on 15-second values obtained from anemometers with indicating dials can presumably be even greater still.

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551.551.5:629.13

LETTERS TO THE EDITOR

Severe low-level turbulence

May I submit a possible explanation for the severe turbulence recently reported by Jefferson?[1] Turbulence associated with mountain airflow and with low-level convection are shown to be most unlikely. An alternative source is the downdraughts produced by the evaporation of falling rain.[2]

The published charts show a synoptic pattern which typically has an extensive band of medium cloud preceding an upper cold trough, and the reported complete cover of cloud throughout the period of turbulence supports this. This cloud often contains convective elements since the mid-troposphere is typically potentially unstable. The tephigrams shown suggest that castellanus clouds were present, base around 600 mb, and this is confirmed by the reports of turbulence in cloud. Such cloud typically gives outbreaks of rain, often evaporating before reaching the ground, with the result that local downdraughts of cold air are initiated. If it reaches the surface, a downdraught causes a short-lived temperature fluctuation, but a more characteristic feature is a temporary rise of pressure. If the outbreaks of rain are widespread (the cloud is then usually reported as $C_M = 9$ or 7) then the barogram becomes very erratic.

Sporadic outbreaks of rain such as this are typically some tens of kilometres across at most, although the downdraughts they produce may spread further, so that the pressure pulses take some tens of minutes to pass overhead (depending on the wind speeds in mid-troposphere). The thermograms and barograms reproduced by Jefferson give ample evidence for the existence of downdraughts. They might be confirmed by reference to outbreaks of rain, or to gusty winds, over Cyprus.

It is likely that downdraughts such as these can on occasion be sharp-edged with a structure resembling that of mamma below a cumulonimbus anvil. An aircraft flying through such downdraughts would experience considerable turbulence, even at levels below that at which the rain evaporates completely.

Anti-locust Research Centre D. E. PEDGLEY
College House, Wrights Lane, London W8

Reply by Mr G. J. Jefferson :

The suggested explanation of this occurrence of turbulence by Mr Pedgley is very interesting.

An inspection of the hourly reports from Akrotiri from 1200 GMT, 14 April to 0600 GMT, 15 April 1966 show that :

(i) No precipitation fell except some slight rain from 0400 to 0500 GMT.

(ii) Gusts were reported as follows :

Date	Time GMT	Gust *knots*	Date	Time GMT	Gust *knots*
14.4.66	1300	22	14.4.66	1600	24
	1400	25	15.4.66	0600	22
	1500	27			

(iii) There was a complete cloud cover throughout. Cloud was reported as a mixture of altocumulus and altostratus throughout the period (medium cloud type 7) from 1200 to 0300 GMT inclusive on the 14th with lowest base 9000 feet. From 0400 to 0600 GMT on the 15th there was additionally some broken stratocumulus at 4500 feet and 1/8 of stratus at 800 feet at 0600 GMT.

There were no reports of mamma structure at Akrotiri and my recollection is that the base of the cloud in the area had a smooth appearance. It is possible though that farther south over the sea where the turbulence occurred the base may have been more disturbed. Other facts noted in the Akrotiri observation register were that pressure falls of 1 mb or more occurred between 1400 and 1427 GMT and between 1900 and 2000 GMT on the 14th ; pressure rose by 1·9 mb between 0300 and 0400 GMT on the 15th. All these facts are consistent with the pressure oscillations mentioned in my article.

Further contributions :

Mr S. G. Cornford reports that when the Hastings aircraft of the Meteorological Research Flight was in transit over the mountainous peninsula east of Sharjah at the south-eastern end of the Persian Gulf on 16 December 1964, moderate to severe turbulence was experienced in clear air at 8500 feet during the flight under evaporating rain falling from thick cloud. This turbulence also might have been caused by downdraughts arising from the evaporating precipitation but it cannot be proved.

Dr W. T. Roach points out that, although turbulence can be produced by thunderstorm downdraughts induced by evaporation, the rate of precipitation from medium-level cloud on this occasion would be much less than in thunderstorms and incapable of producing more than feeble downdraughts. He considers that the primary causes of turbulence in this instance are the factors (*c*) and (*d*) quoted in Jefferson's paper, with factor (*a*) probably occurring as a result of (*c*) and (*d*).

(It would be interesting to know if turbulence of any severity has been recorded elsewhere in circumstances where it can be conclusively associated with evaporating rain. Ed. M.M.)

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REVIEWS

Catalogue of meteorological data for research, First Edition, Part I, WMO Tech. Paper No. 86. 9¾ in × 7½ in, pp. xix + 280, Secretariat of the World Meteorological Organization, Geneva, 1965. Price: Sw.F.30.

There are many research meteorologists who will welcome this volume not only for itself, but also as evidence that the problem of disseminating observational data for research is recognized as a serious and pressing one by the World Meteorological Organization (WMO) and the International Union of Geodesy and Geophysics authorities. In recent years we have been greatly indebted to the Weather Bureau of the U.S.A. for their indispensable publication, *Daily Series, Synoptic Weather Maps*, until recently published in printed form. These, taken together with their other publications, including the U.S.A. climatological data, storm data, and hourly precipitation data, set an altogether splendid example and made the data published on microcards by the WMO for the International Geophysical Year seem by comparison not only inconvenient and expensive, but even sparse. In my own experience the ordinary publications of national weather data by some European countries are remarkably incomplete and primitive, and liable to such accidental errors as the use of incorrect station numbers and the printing of identical soundings on consecutive days. And who would guess that Norway, a country renowned for the prowess of its meteorologists, does not at present publish any daily surface or aerological data at all?

The present loose-leaf catalogue, which will be kept up to date by published amendments, contains lists of all the kinds of synoptic and climatological data regularly or occasionally published by member countries of the WMO and, moreover, the addresses of the authorities which can supply the publications. It will be a most useful reference to many who wish to make conventional case-studies using synoptic data or climatological studies. Others, who might need more detailed data, for example the logs of meteorological radars or reconnaissance aircraft, hourly or half-hourly surface data, autographic records, or the original records of balloon soundings, might like to know that many services show a commendable willingness to be helpful, but all workers are well advised in the introduction to the catalogue to consult the permanent WMO representative of their own country before making their requests for assistance.

F. H. LUDLAM

The dynamics of the upper ocean by O. M. Phillips. 9 in × 6 in, pp. vii + 261, *illus.*, Cambridge University Press, Bentley House, Euston Road, NW1, 1966. Price: 60*s*.

The bibliography of this monograph by Professor Phillips scarcely has an entry dated before 1955 and this alone gives a measure of the book. It is the modern viewpoint of the dynamics of the ocean and has been created mainly in Great Britain and the U.S.A. by fluid dynamicists and oceanographers with decidely mathematical bent. The standpoint is far from Vaughan Cornish,[1] or even Lamb,[2] and reading the book is far from easy; but then no subject makes easy reading when pursued near the borders of knowledge.

After an introductory chapter which deals with the equations of motion there are the four main chapters, two on surface waves, one on internal waves and one on oceanic turbulence. By far the greatest attention is paid to surface waves because they are the easiest to observe and more data are available for testing hypotheses.

The main interest of the meteorologist will probably lie in the treatment of the generation of waves by wind where the effects on the pressure fluctuations of the turbulent wind eddies and of the irregular surface are clearly differentiated and treated separately. The author shows how the turbulent pressure provides the source of energy into the waves and the pressure fluctuations produced by the wave shape selects certain components for amplification through the non-linear processes. The dynamics of the matched layer which is near to the air–sea interface, the momentum flux, the energy flow between wave lengths, the generation of a wave spectrum with an equilibrium range and the breakdown of the waves are all treated and it looks as though a meteorologist who is interested in transfer problems between the sea and the air will have to read this account very carefully ; it is probably not available except scattered through the literature.

Internal waves seem to be less well documented and are consequently less discussed ; they may be of less importance to the meteorologist. The treatment of oceanic turbulence looks more familiar because the same treatment has been given in meteorological papers for atmospheric turbulence and many of the results are similar. The importance here lies in the behaviour of the thermocline and the consequent changes in conditions at the interface affecting the fluxes of momentum and heat ; understanding of these processes which provide energy sources and sinks for the atmosphere is generally recognized as being necessary if advances are to be made in our understanding of the energy flows in the atmosphere.

I am not competent to say what service Professor Phillips has rendered to oceanographers by writing this book. He has provided a very necessary service to meteorologists who have to study the oceanic boundary layer by summarizing what is the modern view of local exchange processes. So far, meteorologists have usually needed to account for these processes on the global scale and this work may aid both by allowing a large-scale view to be built up by integration and also by stimulating research on smaller-scale motions.

E. KNIGHTING

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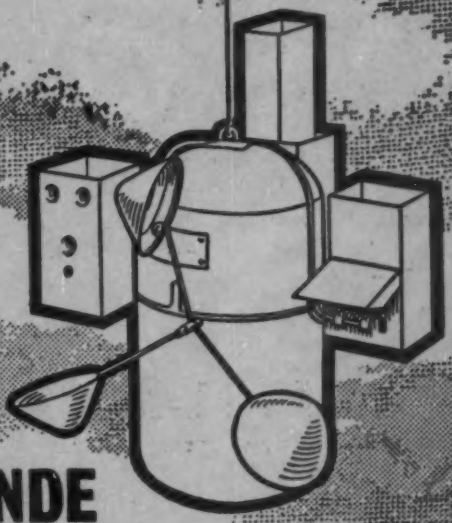

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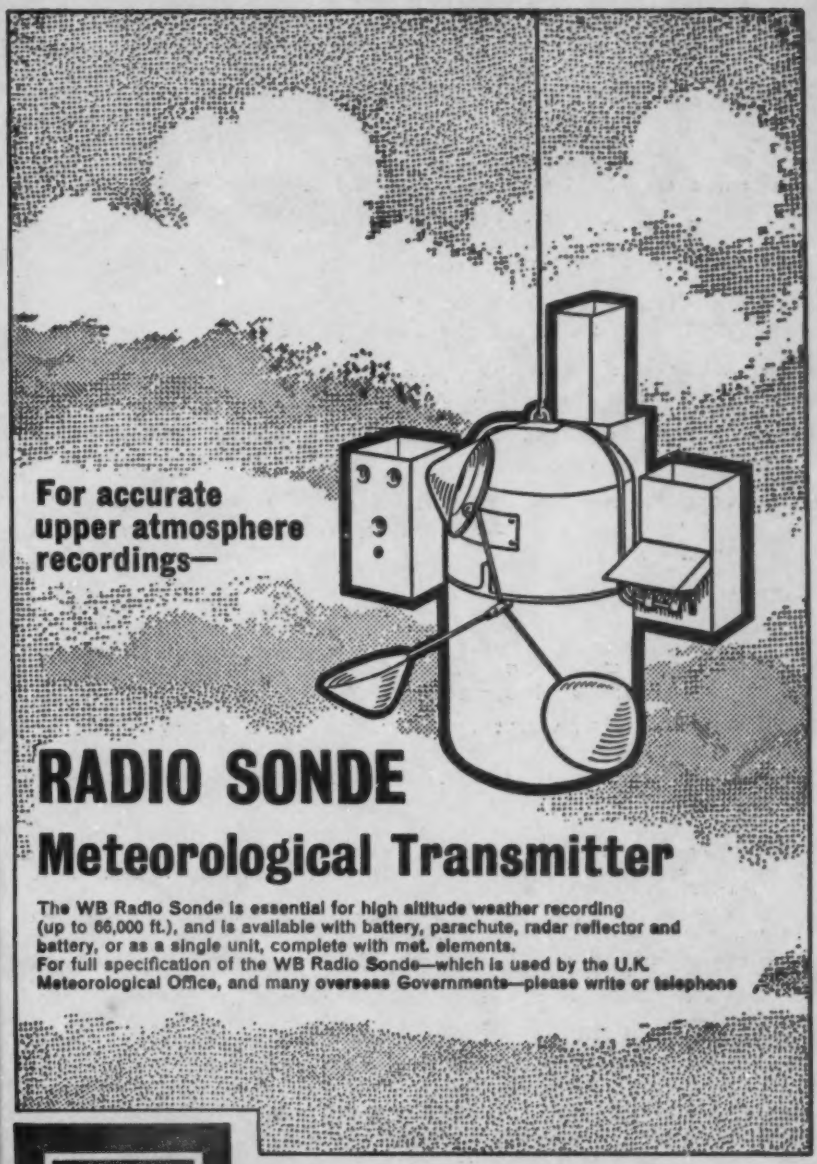
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Printed in England by The Bourne Press, Bournemouth, Hants.
and published by
HER MAJESTY'S STATIONERY OFFICE

Three shillings monthly **Annual subscription £2 1s. including postage**
Dd. 125614 K16 3/67 S.O. Code No. 40-43-67-3